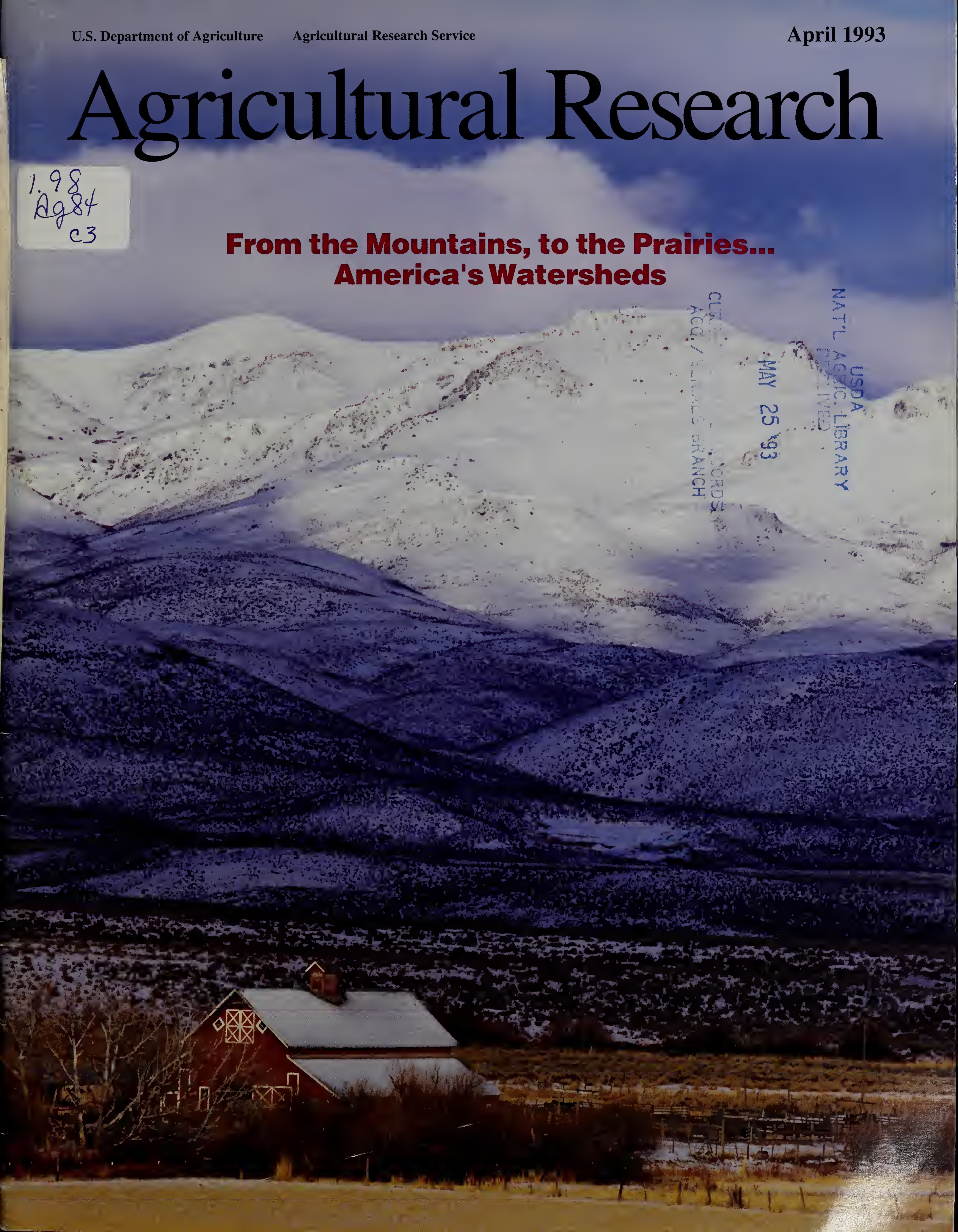
U.S. Department of Agriculture Agricultural Research Service April 1993

Agricultural Research

From the Mountains, to the Prairies... America's Watersheds



FORUM

Looking for Watershed Answers

Water, in its liquid form, is as vital to 20th century life and prosperity as it was to our prehistoric ancestors. A fundamental necessity of all biological entities and processes, water has always been linked to human evolution and destiny.

Lakes, ponds, rivers, streams, and their environs provide both habitats and food for wildlife. And they allow millions of outdoors enthusiasts to enjoy innumerable recreational opportunities.

But how often do we think about the origin—or protection—of this precious, yet commonplace commodity?

One critical component of the evaporation/rainfall cycle that is often overlooked is the millions of acres of watersheds where surface water collects and moves along, creating countless miles of riparian ecosystems and serving as reservoirs from which users take the water they need.

On the surface, this hydrologic cycle seems to be a continuous and simple process, one without beginning or end, natural and timeless. It pretty much works well and maintains itself. But occasionally, serious problems arise and provoke one of humankind's profoundest wishes: to modify or control this water-delivery cycle.

The problem hasn't necessarily been that of having too little water. It's been having too little water where it was wanted or needed and too much elsewhere.

Californians know this all too well. Plagued by drought in the late 1980's and early 1990's, Californians were happy when it finally rained—until so much rain fell so fast that flooding rivers caused extensive damage and created an emergency in some areas.

It was definitely a case of having too much of a good thing, within too narrow a time span.

But similar problems have occurred in many other places as population has grown and suburbs have encroached on farmlands. Increased demand for water, the need to protect water quality by minimizing agrichemical runoff and soil erosion, and control of water in flood-prone areas have become increasing challenges.

Fortunately, resource planners and legislators saw them coming. Back in 1954, the U.S. Congress enacted the Watershed Protection and Flood Prevention Act. It was designed to coordinate federal, state, and local efforts to prevent flooding and establish agricultural methods to minimize the impact of farming on watersheds.

But that act was just one in a series of water-related enactments between 1948 and 1965, when provision was made for creation of water quality standards for interstate streams. Thus, it was steadily—over several decades—that Congress moved toward defining a national strategy for managing water resources.

It could be said that Congress actually launched the nation's comprehensive water quality plan when it passed the Federal Water Pollution Control Act Amendments of 1972 and the changes of 1977, 1982, and 1987. Together, all that legislation makes up what is called the Clean Water Act.

Those legislative actions greatly expanded the role of watershed research in water quality management. Addressing them has been a major component of the ARS program for almost a quarter of a century.

And national and international concerns about the potential effects of increased concentrations of thermal gases in the atmosphere on climate, hydrology, and water resources have also added a new dimension to ARS watershed research.

So it would appear that while issues swirling around water quality and use are increasingly complex and provocative, the fundamental importance of watersheds is recognized anew. In a December 1992 report titled "Water Quality: Agriculture's Role," the Council for Agricultural Science and Technology stated, "While there is continuing interest in groundwater, surface water protection has gained renewed interest, and new programs are being developed to protect all water resources on a total watershed basis."

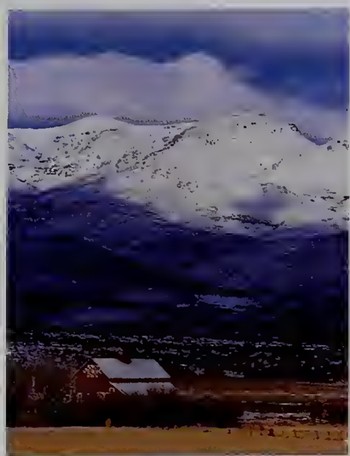
As part of long-term, ongoing efforts by the Agricultural Research Service to address important water quality issues, ARS scientists are working on watershed management problems at 15 research stations around the country.

This month, *Agricultural Research* highlights progress being made at six locations, from South Carolina to Idaho. We still don't see the total picture, but ARS is making big strides toward better understanding the complex processes that occur throughout the nation's watershed areas.

And we already know they are an earthly link to the water cycle that bathes and sustains all of the planet's life.

Linda R. McElreath
Associate Editor

Agricultural Research



Cover: Site of the 90-square-mile Reynolds Creek Experimental Watershed in the Owyhee Mountains about 50 miles southwest of Boise, Idaho. Photo by Scott Bauer. (K5060-02)

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Vol. 41, No. 4
April 1993

Editor: Lloyd McLaughlin	(301) 344-2514
Associate Editor: Linda McElreath	(301) 344-2536
Art Director: William Johnson	(301) 344-2561
Contributing Editor: Jeanne Wiggen	(301) 344-2502
Photo Editor: John Kucharski	(301) 344-2900
Assoc. Photo Editor: Anita Daniels	(301) 344-2956

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Agricultural Research is published monthly by the Agricultural Research Service, U.S. Department of Agriculture, Washington, DC 20250-2350.

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Subscription requests should be placed with New Orders, Superintendent of Documents, P.O. Box 371954, Pittsburgh, PA 15250-7954. Please see back cover for order form.

This publication was printed with soybean oil-based inks.

When writing to request address changes or deletions, please include a recent address label.

Address magazine inquiries or comments to: The Editor, Information Staff, Room 408, 6303 Ivy Lane, Greenbelt, MD 20770

Mike Espy, Secretary
U.S. Department of Agriculture

R.D. Plowman, Administrator
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Robert W. Norton, Director
Information Staff

Protecting—and Taming—Watersheds

"To rule the mountain is to rule the river."

The one who penned this ancient Chinese proverb knew something about watersheds—those webs of streams, creeks, and rivers fed by rain and melting snow filtering down from the mountains and hills into the valleys below.

It's easy to look at a quiet, meandering creek and not remember that it is connected to larger streams and rivers that eventually drain into lakes and oceans. And it's easy to see individual pieces of a watershed, but much harder to envision the whole—unless, as the Chinese proverb suggests, the quiet creek turns into a raging river that washes away everything in its path.

"All things, including weather and rainfall, change fast, and our memories are short," wrote Alfred Stefferud, editor of the 1955 Yearbook of Agriculture, which was devoted to water resources. "When it rains, we forget about the dustbowl; when it is dry, we forget about floods."

The need to rule the river still exists today. So scientists with the Agricultural Research Service are studying watersheds to understand the forces that make them rise and fall. It's a complex undertaking, because there are thousands of watersheds in the United States, each with its own topography, soils, climate, land use, and geology.

ARS maintains a network of 15 watershed research stations throughout the country. A closer look at six of these watersheds—in Idaho, Arizona, Oklahoma, Iowa, Georgia, and North Carolina—illustrates how USDA scientists look for better ways to predict when upstream water will be available to farmers and ranchers downstream. They're also working on ways to minimize erosion caused by rain and snow and to improve water quality.

Herrings Marsh Run: Protecting Water Quality in Heavy Production Areas

Agricultural practices can adversely affect watersheds. Fertilizers, runoff from poultry, swine, and cattle farms,

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ARS agricultural engineer Kenneth Stone (right) and hydrologic unit aid Ronnie Warren sample groundwater from a shallow well near a poultry production and manure composting site to check for pollutants. (K5053-06)

Mahantango Creek watershed near Klingerstown, Pennsylvania. The combination of land use, soil properties, and hydrogeology largely determine vulnerability of surface and groundwater to contamination by agricultural activities. (K5051-05)

and effluent from other agricultural operations can seep into streams, rivers, and wells unless preventive steps are taken.

A 5-year study in North Carolina is part of a long-term ARS effort to gauge the effects of farm operations on watersheds—and to help improve water quality in those environmentally sensitive areas.

In 1990, scientists began the study in the Herrings Marsh Run watershed in Duplin County, North Carolina. It's one of the eight original demonstration projects funded under the U.S. Department of Agriculture's Presidential Water Quality Initiative. Several USDA agencies—including ARS, Extension Service, and Soil Conservation Service—as well as several other cooperating agencies—are involved in the project.

Duplin County is one of the leading agricultural areas in North Carolina. In 1990, it had the highest population of turkeys—and the fourth highest swine population—of any county in the United States.

The 5,050-acre Herrings Marsh Run is typical of an eastern coastal plain watershed. It has predominantly sandy soils and intensive agricultural practices, including 2,700 acres of cropland, 1,750 acres of woodlands, and 525 acres of farmsteads, poultry, and swine facilities, says Kenneth C. Stone, an agricultural engineer with ARS in Florence, South Carolina.

The North Carolina Cooperative Extension Service estimates that in the watershed, farmers use 160 tons of nitrogen, 70 tons of phosphorus, and 267 tons of potassium as fertilizer. About 90 percent of all nutrients applied in the watershed come from commercial fertilizers, he says, even though swine and poultry operations generate enough waste to supply half the nutrients needed in the watershed. Excess waste often washes away into surface water.

To monitor groundwater, 25 wells were installed on six farms. To gauge stream water quality, three sampling

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Soil scientist Ronald Schnabel (left) and hydrologic technician Earl Jacoby study natural riparian zone processes that lessen the impact of upstream agriculture on water quality. (K5050-03)

stations were established on tributaries, including one downstream from an animal production area, says Stone, who is based at the Coastal Plains Water Conservation Research Center in Florence. A fourth was set up at the watershed outlet.

Researchers have collected 2 years' worth of data. While preliminary results show that the quality of most of the stream and groundwater is acceptable, Stone says agriculture has harmed water quality in some areas.

The biggest problems apparently stem from over-application of nitrogen from either commercial fertilizers or waste from poultry and swine facilities. Nitrates, ammonia, and phosphorus are the main contaminants from fertilizer and animal waste. They can spur the growth of algae and other organisms that consume oxygen in the water, choking off fish and other wildlife. At high levels, they can also be toxic to fish, wildlife, and humans.

"The highest levels of nitrate-nitrogen contamination of groundwater occurred at a farm where swine wastewater was sprayed on grassland," says Patrick G. Hunt, research leader at the Florence lab. "Levels there ranged from 28 to 74 milligrams per liter—far exceeding 10, the acceptable level."

The main reasons: The field wasn't large enough to handle the volume of wastewater, and it didn't then have a permanent grass cover to help absorb the waste.

"Groundwater is particularly vulnerable in watersheds like this," Stone says, "because of the sandy soils and because the water table is only 5 to 10 feet below the surface."

Higher-than-acceptable levels of nitrate-nitrogen were also found in wells on several other farms, possibly caused by excessive field application of commercial fertilizer and poultry litter.

Of the tributary stations, two showed low nitrate-nitrogen, ammonium-nitrogen, and ortho-phosphorus levels because they were buffered from runoff. But the third tributary, in an area of intensive swine and poultry operations, had 5 times higher levels of nitrate-nitrogen, 15 times more ammonium-nitrogen, and 10 times more ortho-phosphorus than the clean tributaries. Nutrient levels in the watershed outlet fell between those found in the clean and contaminated tributaries.

Stone says USDA's Extension Service and Soil Conservation Service are working with farmers in the watershed to better manage their operations to improve water quality. One key finding so far is that farmers may be over-applying nutrients in some areas of the watershed. "There are more nutrients going into some portions of the watershed than can be assimilated by the crops and riparian, or streambank, ecosystems," he says.

He also believes farmers can make better use of nutrients in animal wastes, thereby reducing the need for commer-

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Above: In the winter months, a snow cat provides access to the precipitation gauges in the Reynolds Creek watershed. Probes buried in the soil allow technician Delbert Coon to record frost depth. (K5058-03)

Below: Technician Delbert Coon examines the snowfall collected in a precipitation gauge on the solar-powered telemetry system at the Reynolds Creek watershed. (K5061-08)

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cial fertilizers, improving water quality, and cutting costs.

Reynolds Creek: Forecasting Water From Snowmelt

Snow flurries first dust Idaho's Owyhee Mountain range around mid-November. By January, the drifts atop Reynolds Mountain may be 20 feet deep. At 7,390 feet, this snow-capped ridge is the highest point in the Reynolds Creek Experimental Watershed, ARS' westernmost watershed. Located 50 miles southwest of Boise, Idaho, this 90-square-mile watershed is the only ARS location that conducts field studies on snow.

Between 50 to 80 percent of the western U.S. water supply originates from mountain snowpacks such as this, says Keith R. Cooley, a hydrologist in the Northwest Watershed Research Unit.

"One of our main goals is to develop accurate models to forecast water supplies," he says. These models incorporate snow-volume and other data taken over several years. The forecasts help ranchers and farmers make the best use of limited livestock and irrigation water supplies. And water-dependent industries like salmon fisheries and hydroelectric power plants also need the water supply information.

But unevenness in snowpacks makes forecasting difficult. Just a stone's throw away from a 20-foot-deep drift may be bare ground—the result of 40 mph winds that howl across the open rangelands. From above, the landscape may resemble a patchwork pattern of dark and light.

On average, every 10 inches of snow melts down to 1 inch of water, but yield depends on the type of snow. Heavy, wet snow holds more water than snow that's light and powdery—the sort that usually falls near Reynolds Creek.

To estimate the snow's water-yield capacity, researchers weigh it, using a device called a snow pillow that resembles a 10-foot-diameter waterbed filled with antifreeze. When snow falls on top of the rubber "pillow," its weight pushes the antifreeze into a tube connected to a pressure gauge that gives a reading of the snow's weight.

This reading—along with other data from other snow measurement sites on the watershed, checked twice monthly—provides numbers used to create and test models for predicting water supplies.

One of these, developed by engineer Gerald N. Flerchinger and called SHAW (Simultaneous Heat and Water), uses weather data and soil temperatures to simulate snowmelt. It takes into account factors that tend to slow the melt, such as sagebrush thickets covering the soil.

"The snowmelt data can then be plugged into a model that predicts how long it takes water to get from a melting snowdrift into a stream," says Flerchinger. Melted snow percolates through the soil and permeable rock into shallow aquifers that eventually drain into streams.

"Streamflow responds much more rapidly to snowmelt and waterflow through these underground channels than we originally thought," says Flerchinger. For some time, researchers had attributed this quick response to overland flow, or melted snow moving above ground. Because only water moving above soil can erode it and cause stream pollution, the finding is good news for environmental protection.

Weather records from the Reynolds Creek site have also proven valuable for a new computer model called USCLIMAT.BAS. Agricultural engineer Clayton L. Hanson developed the model with fellow ARS colleagues Kirk A. Cumming (also at Boise), David A. Woolhiser, recently retired from the watershed lab in Tucson, Arizona, and Clarence W. Richardson, from the grasslands lab in Temple,

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On a watershed near Ames, Iowa, technician David Joplin measures soil moisture using a neutron probe meter. (K4536-12)

Texas. The model can be used to provide a simulated weather record for any place in the United States.

"We can't use these records to forecast the weather," says Hanson. "But we can use them to generate weather data to plug into other models to estimate growth of plants or movement of fertilizer or other chemicals into water supplies."

Walnut Gulch: A Rangeland Watershed

Like other areas under study, the Walnut Gulch Experimental Watershed is an outdoor laboratory charged with developing knowledge and technology needed to preserve our natural resources for future generations.

Researchers began collecting data in 1954 in Walnut Gulch, a 58-square-mile watershed that drains into the San Pedro River near Tombstone, Arizona, site of the infamous gunfight at the O.K. Corral. This rolling, arid land in the southeast corner of the state would make a perfect setting for an action-packed, western movie. Filming would be easy too; it only rains 10-20 inches a year, mostly during July and August.

"Walnut Gulch has the distinction of being the world's most measured watershed. We have rain gauges, runoff-measuring flumes, and meteorological weather stations strategically placed to gather data from 22 subwatersheds that represent the various soil types, vegetation, and land uses present," says Leonard J. Lane, head of the ARS Southwest Watershed Research Center in Tucson. The watershed is classified as rangeland—a land type that covers roughly 40 percent of this planet's land mass.

"When we started data collection 38 years ago, we had no idea how valuable it would be in understanding and protecting not just our rangelands in the American Southwest, but also in understanding ecosystems on a global scale," says Lane. "Some of that early data is used today in sophisticated computer programs to provide possible scenarios of how small, localized changes in watersheds such as Walnut Gulch can influence climate change."

These changes could include shifts from rangeland to cropland and vice versa, invasion of weeds and shrubs, reduction in range fires, and conversion of grazing lands to urban use.

Major areas of study at Walnut Gulch include erosion and sedimentation, hydrology, water quality, and global change, or the effects of long-term shifts in temperature and carbon dioxide levels on the Earth.

Representative projects include predicting floods; developing computer programs that simulate erosion, pesticide movement, and plant growth; predicting soil loss under various farming and ranching operations; and developing an improved scientific basis for making decisions in natural resource management.

"The newest computer model incorporating data from Walnut Gulch is called RUSLE, short for Revised Universal Soil Loss Equation. It's now in use by USDA's Soil Conservation Service and should be available to county agents later this year," says Kenneth G. Renard, ARS hydraulic engineer in Tucson.

"RUSLE is vastly more accurate than the original 1950's version, thanks to additional data from Walnut Gulch, the refinement of formulas, and advances in computer technology. With this tool, farmers and ranchers can make decisions about crops, tillage, and range improvement practices that reduce the amount of soil erosion."

Southern Piedmont: The Effects of Ill-Timed Rain

The Southern Piedmont receives an average of 50 inches of rainfall a year. That should be enough to grow a profitable crop. Unfortunately, ill-

To determine streamflow, technician Donna Schmitz measures the depth of the pool on the upstream side of a V-notch weir and applies a formula designed for this weir. (K4525-12)

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timed rainfall can be disastrous to farmers. Either the rain doesn't come when needed, or too much comes all at once and the soil washes into streams, says soil scientist George W. Langdale.

The Southern Piedmont extends from Virginia southwest through the Carolinas, Georgia, and into Alabama. It is a rolling plateau lying between the Blue Ridge Mountains and the southeastern coastal plain.

Over the past two centuries, heavy rainstorms caused severe erosion on Southern Piedmont cottonfields. This erosion still creates problems for farmers, often leaving them a shallow, acid soil that needs additional lime, fertilizer, and organic matter to make it productive.

A storm that typifies the region's vulnerability to rain-caused destruction occurred in late May 1973. Four inches of rain fell in 24 hours on a research watershed at the Southern Piedmont Conservation Research Center in Watkinsville, Georgia. Worse yet, the storm came just days after soybean seedlings began to emerge in fields. About half the rain left the fields, carrying away almost 8 tons of soil per acre.

A recent analysis of 19 years of data on the watershed has convinced Langdale that the 1973 storm was 1 of only 11 that together caused 42 percent of the soil loss during that period.

While farmers can do nothing about controlling the severity and timing of major storms, there is hope. Almost all of the 12 tons of soil per acre lost in the two decades since the experiment began has been from the first few storms, back when soybean fields were plowed and planted to grow one crop a year, from 1972 to 1974. "That was the norm for soybean planting at the time," Langdale recalls.

But his study shows that farmers can beat the erosion odds by putting aside their moldboard plows and disk harrows and by planting two crops a year.

Beginning in 1974, Langdale used no-till and other conservation tillage implements to plant soybeans or grain sorghum directly into the remnants, or residue, of a winter crop of wheat, barley, forage sorghum, or crimson clover—with minimal soil disturbance. These fields almost completely resisted erosion—no matter how hard, how long, or at what time of year it rained. Even 6 inches of rain in an October storm in 1989 failed to move more than 9 *pounds* of soil per acre off the watershed fields.

Findings from these studies will help farmers comply with the 1990 Farm Bill's voluntary soil erosion standards, which go into effect in 1995.

Crop residue management includes conservation tillage as well as other tillage methods that meet erosion goals with less than 30 percent residue left on the surface.

According to William Richards, former chief of USDA's Soil Conservation Service, the Department is emphasizing residue management because farmers chose that method to meet erosion standards on about 75 percent of the acres in their compliance plans.

Farmers are already managing residues, instead of plowing them under, on 162 million acres of cropland—57 percent of the nation's total—according to Dan McCain of the Conservation Technology Information Center in West Lafayette, Indiana.

Treynor: Protecting Vulnerable Loess Soil

In midsummer, the rolling hills of the Treynor watersheds in southwestern Iowa are an endless sea of green. Field corn, slated for the stomachs of farm animals, has been grown here every year since 1964.

Beneath the hardy stalks lies a deep, rich loamy soil known as loess. This soil traps and holds water well—a boon to the thirsty crops.

Unfortunately, loess soils are also prone to erosion. Drenching summer rainstorms carve small gullies between

A 2-acre pothole (area of low wetland) in a soybean field is being studied to determine water movement, chemical transport, and the fate of agricultural chemicals in saturated soils. (K4535-11)

crop rows and carry away soil particles that clog creeks, streams, and rivers. Some of the finer particles end up at the bottom of the Gulf of Mexico.

At the ARS Deep Loess Research Station where the Treynor watersheds are located, scientists are comparing conventional tillage techniques with other methods of tilling and planting designed to conserve loess soil and protect water quality.

The Treynor watersheds include four fields, each between 75 and 150 acres. To date, the most striking findings come from comparisons between segments of the watershed under conventional and ridge tillage.

Over the past 18 years, the conventionally tilled field lost, on average, over 5 tons of soil per acre each year. But the ridge-tilled field lost an average of just over half a ton, says agricultural engineer Larry A. Kramer. Cultivating corn rows that are till-planted in the same position each year forms 6- to 8-inch ridges, which help stop soil from washing away with the rain. Conventional tilling, in contrast, leaves the field smooth from numerous passes with a heavy disk.

"Rain that doesn't run off the surface of the fields percolates down to the upper groundwater table," says Kramer. A process known as groundwater recharge, it accelerates under ridge tilling, compared to conventional tilling.

Water samples taken from seepage that flows into the ditch at the watershed outlet revealed that groundwater recharge from ridge tilling contains 17 mg/L of nitrogen—slightly more than twice the nitrogen found in the seepage water on the conventionally tilled watershed.

The findings show that the water infiltration changes seen under ridge tillage also affect movement of agricultural chemicals in the soil, says Jerry L. Hatfield, director of the National Soil Tilth Laboratory in Ames, Iowa.

"The excess nitrogen in the seepage water isn't being used by the crop," says Hatfield. "That suggests we may need to modify our fertilizer application rates, to avoid putting excess nitrate into the groundwater." Studies to address that problem, and the effects of planting other crops in rotation with corn on the watersheds, are currently under way.

Little Washita: Measuring Water Movement

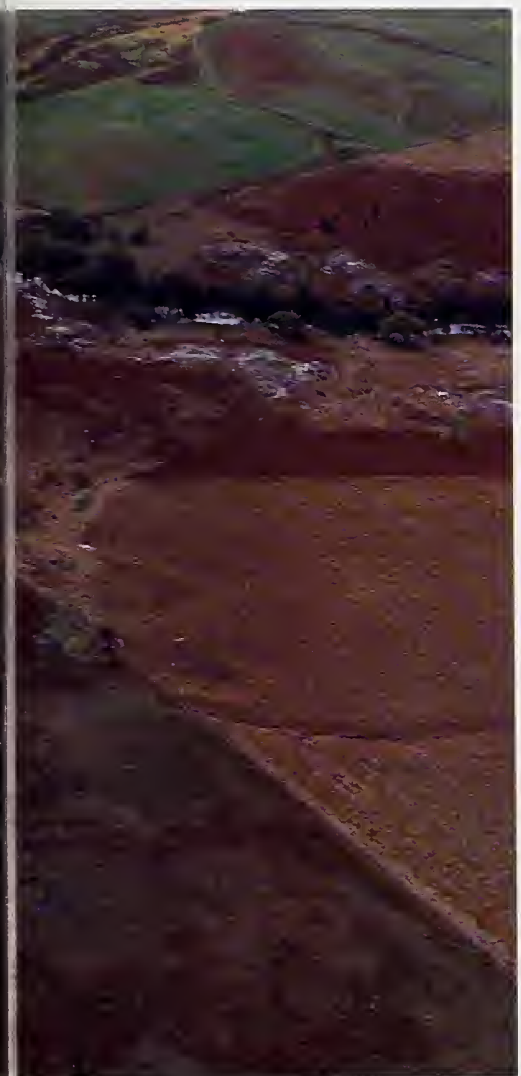
Hydrologists in Durant, Oklahoma, depend on one of the nation's longest-studied watersheds—and some of the newest technology—to forecast how

A small part of the 220-square-mile Little Washita River watershed near Chickasha, Oklahoma. (K5055-06)

agriculture and climate change affect long-term water resources.

Farmers have planted mostly alfalfa and other forage crops on the Little Washita River watershed, located about 50 miles southwest of Oklahoma City, Oklahoma. It is characterized by low-rolling grassland and timberland. The river is actually a tributary that bisects the watershed before feeding eastward into the larger Washita River.

Researchers have relied on the 235-square-mile area as a source of hydrologic data for over 50 years, says Frank R. Schiebe, director of USDA's National Agricultural Water Quality Laboratory in Durant.



Since 1936, state and federal agencies have conducted soil and water conservation studies here, he says. "Currently, the object of our research is to develop computer databases that cover all the hydrologic processes taking place on a watershed," Schiebe says. "We're also trying to develop improved computer models to enhance our ability to describe these processes."

He says older weather stations are being upgraded and spaced every 3 miles on the watershed to better record data for air and soil temperature, humidity, atmospheric pressure, solar radiation, moisture, and precipitation.

"On the Little Washita itself, we've installed new stream gauges to measure flow discharge at several points in the river," adds Schiebe.

Researchers with ARS and the National Weather Service (NWS) have also begun testing WSR-88D, which is new radar technology formerly called NEXRAD—Next Generation Weather Radar—to measure aerial precipitation rates. Last spring, three of these new radars were installed within 60 miles of the Little Washita River watershed. The measurements they provide can be used to forecast how runoff from rain could affect soil or water resources.

"We cooperated with the NWS in a project called STORM-FEST (Fronts Experiment Systems Test) and we looked at rainfall in detail to help them calibrate their new instruments," Schiebe says.

Computer simulations of runoff—based on WSR-88D's estimates—are now being compared with records of runoff taken by stream gauges on the watershed.

Schiebe expects that precipitation estimates from WSR-88D will enhance the databases used by water resources modelers. "Cooperating with other agencies allows us to leverage our efforts in order to achieve more research than we could using only our own resources," he says.

While only three of the new radars that have been installed are being tested by ARS and NWS, more than 100 will be set up across the nation in the next 10 years to improve weather prediction.—By **Julie Corliss,** formerly ARS. **Sean Adams, Don Comis, Dennis Senft,** and **Jan Suszkiw,** all from ARS, contributed to this article.

Kenneth C. Stone and Patrick G. Hunt are at the USDA-ARS Coastal Plains Water Conservation Research Center, Box 3039, Florence, SC 29502. Phone (803) 669-5203, fax number (803) 669-6970.

Keith R. Cooley, Gerald N. Flerchinger, Clayton L. Hanson, and Kirk Cumming are at the USDA-ARS Northwest Watershed Research Laboratory, 800 Park Blvd., Plaza IV, Suite 105, Boise, ID 83712. Phone (208) 334-1363, fax number (208) 334-1502.

Leonard J. Lane and Kenneth G. Renard are at the USDA-ARS Southwest Watershed Research Center, 2000 E. Allen Rd., Tucson, AZ 85719. Phone (602) 670-6381, fax number (602) 670-6493.

George W. Langdale is at the USDA-ARS Southern Piedmont Conservation Research Center, Watkinsville, GA 30677. Phone (706) 769-5631, fax number (706) 769-8962.

Larry A. Kramer is at the USDA-ARS Deep Loess Research Station, Rte. 2, Box 132A, Council Bluffs, IA 51503. Phone and fax number (712) 487-3403.

Frank R. Schiebe is at the USDA-ARS National Agricultural Water Quality Laboratory, P.O. Box 1430, Durant, OK 74702. Phone (405) 924-5066, fax number (405) 924-5307. ◆

Bottom Ash Boosts Poor Soil

Heavy with fruit, the limbs of the trees almost touch the ground. Big, luscious-looking apples, deep yellow streaked with red, cover trees in two orchard rows.

"Don't pick from those trees!" admonishes Ronald Korcak. "We need to get yield data from them."

The picture-perfect fruit in this particular section of the orchards at the Beltsville Agricultural Research Center hang from Gala apple trees that are part of ongoing soil experiments.

Korcak, research leader of the ARS Fruit Laboratory in Beltsville, Maryland, is using industrial byproducts in three ways: as a limestone substitute, to increase calcium levels in both soil and plants, and as a gypsum-containing soil amendment.

In addition to benefiting soil and plants, agricultural use of these industrial byproducts also provides for environmentally sound disposal.

In 1980, Korcak applied fluidized bed bottom ash, a byproduct of coal-fired power generation, to the surface of the soil under the apple trees.

This ash is the residue from burning groundup limestone and coal together in power plants that generate electricity. Sulfur in the coal reacts with calcium from the limestone, forming gypsum and calcium oxide in a process called fluidized-bed combustion (FBC). [See *Agricultural Research*, April 1989, p. 9.] FBC bottom ash is a dry, alkaline byproduct high in acid neutralizers and gypsum.

At traditional power plants, limestone is not mixed with coal in the combustion process, and the ash does not contain gypsum.

Korcak estimates that coal-burning utilities generate over 88 million tons of waste annually. By the year 2000, this amount will increase significantly. Bottom ash from the FBC process accounts for only a small percentage of this. "However," says Korcak, "FBC and other clean-coal technologies should result in reduced emissions and the potential for decreased acid rain."

Having a texture similar to that of sand, FBC bottom ash modifies the structure of clay soil. When applied in small amounts, it improves aeration, increases water infiltration rates, and makes cultivation easier.

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Soil scientist Ron Korcak has tested fluidized bed bottom ash from power plants and washings from cement trucks (shown here) in apple orchards at the Beltsville (Maryland) Agricultural Research Center. (K4943-18)

"We applied 50 tons of FBC bottom ash per acre to study how it affects the soil and then on trees and fruit," Korcak explains. This was a one-time, surface application. Not only was the resulting fruit attractive and plentiful, but the trees were vigorous and healthy.

The fruit showed no nutritional problems from the ash, he reports, and calcium and pH levels in the soil increased significantly. Although the ash remained on the surface, the pH increased down to a depth of 8 feet.

"The ash particles fused together to form a porous, cementlike cap on the soil surface that prevented weed growth for about 4 years after application," Korcak says. "And over 6 years, cumulative yields were increased in three of the four apple varieties in the FBC plots."

Although the cap on the soil surface is crusty, it is porous enough to allow water to seep through.

Gypsum from FBC bottom ash nourishes crops by adding calcium and sulfur to the soil. The higher calcium levels lead to better quality fruit and more disease-resistant trees, he says.

"We've had good results growing sudangrass with bottom ash in greenhouse tests," says K. Dale Ritchey. "We've seen a substantial improvement in rooting depth, indicating that with this soil additive, plants can better withstand drought by going deeper into the soil for moisture."

A soil scientist at the ARS Appalachian Soil and Water Conservation Research Laboratory in Beckley, West Virginia, Ritchey is using other coal-combustion byproducts from flue gas desulfurization, called scrubber sludges, as soil additives.

Ritchey and colleagues at Beckley are testing these byproducts as amendments to the acidic, hilly soils of the Appalachian region.

In addition to apples, Korcak has used bottom ash on tomatoes grown in raised beds. He surface-applied the ash at about 95 tons per acre.

Compared with bare soil and two other commercial surface mulches—black plastic and rolled newspaper—tomato yields and fruit firmness were equal or superior to any other treatment.

"Analysis of tomatoes and plant leaves revealed higher calcium levels than with other treatments," Korcak reports. "Studies continue to test for any adverse effects from the ash."

He is now evaluating this method in larger scale field tests.

The Industry Perspective

John Pizzella, superintendent of fuels byproducts for the Potomac Electric Power Company (PEPCO), says bottom ash is different from other industrial byproducts that may pose a threat to the environment.

"The Environmental Protection Agency does not consider bottom ash a hazardous waste," he says.

PEPCO, which supplies power to more that 650,000 customers in the Washington, D.C., metropolitan area, generates about 175,000 tons of bottom ash a year. This is about 25 percent of the waste byproduct PEPCO produces by the coal combustion process. The remainder consists of fly ash and other residues.

How does PEPCO store bottom ash? "We store some of it at designated ash sites and use some in onsite construction projects," Pizzella says.

"We also supply it to plant nurseries and turf farms. A lot is used to make concrete blocks and for ice control on highways. Horse farm operators like bottom ash because it stays in place better than gravel and is easier to walk on," he continues. "But, we'd like to see more bottom ash used in agriculture. And we do have stockpiles available."

Onsite storage costs range from $10 to $45 per ton, according to the American Coal Ash Association (ACAA). The association represents coal-burning utilities and suppliers of related goods and services in the United States.

They expect this figure to double—and perhaps even triple—over the next several years. Some power companies do not have onsite storage space available and must dispose of their waste through offsite landfills. Offsite costs can range from $35 to $150 per ton, which takes into account transportation and tipping fees at the sites.

And it's becoming more and more difficult to find landfill space.

Making More Use of Bottom Ash

Soil scientist Arthur Peterson, University of Wisconsin, has mixed bottom ash in soils planted with corn for about 8 years and attests to its improving the physical conditions of the Wisconsin soil.

"Our heavy clay soil responded well to bottom ash. We worked it into the soil to a depth of about 8 inches and found that it increased rainwater infiltration considerably," he says.

The success rate of the waste as a soil amendment, Peterson notes, depends on the type of coal from which the product comes and the type of soil it is being applied to.

Ron Korcak displays apples harvested from bottom ash-treated trees. (K4945-9)

SCOTT BAUER

The ACAA confirms the importance of these two factors. Robyne Fillmore, communications director for the association, says that the bottom ash from some types of coal may have better properties for soil use than that from other types.

"The industry produced close to 14 million tons of bottom ash in 1990. Of this, it used only about 5 million tons, primarily in construction and for snow and ice control," Fillmore says. "The remaining 8.5 million tons were either disposed of in landfills or stored by individual plants. It would certainly make a big difference to coal-burning utilities if agriculture could use more bottom ash."

However, there can be a downside to using certain byproducts from coal-fired industrial plants, cautions W. Doral Kemper, ARS national program leader for soil management, based at Beltsville, Maryland. "Although most of the elements in the byproducts are benign, beneficial, and even essential to crop production, heavy metals and some other compounds present can be toxic at excessive concentrations.

"We're accumulating information that will help prescribe appropriate levels of land applications. But we definitely need more research on how elements in the ash interact with different soils and plants."

Meanwhile, Korcak is doing some forward-thinking about the increasing amounts of bottom ash that are piling up.

"One idea we're looking at is what we call byproduct recycling. We could incorporate bottom ash with materials like leaves and yard debris and try this mix in the soil. We're exploring the practicality of designing new soils, a science we call pedotechnology," he says.—By **Doris Stanley,** ARS.

Ronald F. Korcak is with the USDA-ARS Fruit Laboratory, 10300 Baltimore Ave., Beltsville, MD 20705-2350. Phone (301) 504-5650, fax number (301) 504-5062. ◆

SCOTT BAUER

Animal scientist Ted Elsasser weighs a parasite-infected calf that has been treated with growth-regulating hormones. Zoologist Ron Fayer records the information. (K4736-3)

How Parasites Hamper Livestock Growth

Farmers and scientists have long known that livestock animals with parasites grow poorly and never reach their full growth potential. They are called runts or poor doers, and no matter how much they eat they remain undersized.

Although veterinarians and researchers have known for many years that parasites cause these problems, the underlying mechanisms by which infectious agents restrict growth are just beginning to be understood, say ARS scientists Ronald Fayer and Theodore H. Elsasser.

Historically, we have thought that large parasites such as tapeworms in the gut simply robbed the host animal of nutrients needed for normal growth. However, in many cases where animals grow poorly, the parasites or other organisms are too small and too few to directly consume enough food to affect the nutritional status of the host animal. Furthermore, some animals continue to grow poorly long after the parasite is gone.

"For these reasons, we figured parasites and other infectious agents had to be influencing their hosts in ways that we had not detected," says Fayer, a zoologist at the Zoonotic Diseases Laboratory in Beltsville, Maryland.

Recent studies on calves at ARS' Beltsville Agricultural Research Center have provided insight into the complexities of parasite infections as related to poor growth. "We now know that the immune system responds, in part, to invading organisms by producing chemical signals that modify host metabolism," says Elsasser, an endocrinologist with ARS' Ruminant Nutrition Laboratory, Beltsville, Maryland.

These immune response signals—small proteins called cytokines—manipulate the hormones that regulate feed intake, nutrient use, and ultimately, growth of the animals.

"Dairy and beef calves infected with a protozoan parasite called Sarcocystis run a fever, lose their appetite, and become emaciated. But even after they recover from an acute illness, some calves simply fail to grow normally," says Fayer.

Experiments designed to uncover why this is so were set up using three groups of calves.

A control group was made up of uninfected calves that were allowed to eat as much as they desired.

A second group consisted of Sarcocystis-infected calves that were also permitted to eat as much as they desired.

Uninfected calves formed the third group. These calves were fed exactly the same amount of feed that the infected calves ate. This last group of "pair-fed" control calves was used to determine the effect of nutritional intake on growth, separate from other effects of the parasite.

The studies showed that uninfected calves with no feed restriction grew best and flourished, as expected. But uninfected calves fed just the amount of feed the infected calves received still grew at a near-normal

rate, diminishing the possibility that reduction in the quantity of feed eaten by infected calves was the sole cause for poor growth.

In contrast, the infected calves grew to only half the size of the uninfected, unrestricted control animals.

Some Explanations Emerge

Before, during, and after acute infection with the parasite, the concentration of growth-regulating hormones in the blood was measured. "We found that the concentration of a hormone essential for growth—an insulin-like growth factor (IGF-I)—decreased at the same time that another hormone that blocks growth hormone secretion, somatostatin, increased," says Elsasser.

Furthermore, these hormone changes persisted in the infected calves even after the symptoms of infection were gone.

Other researchers have shown that symptoms such as fever, poor appetite, and emaciation in human patients with malaria or cancer are caused by a cytokine released by cells of the immune system.

This cytokine was called both cachectin, because it causes cachexia (emaciation), and tumor necrosis factor (TNF), because it attacks and kills some types of tumors.

Says Fayer, "When we noticed many of the same symptoms—as well as premature growth cessation in cattle infected with Sarcocystis—we decided to see if TNF played a role by affecting those growth-regulating hormones that we had found altered in the parasitized calves."

"Tumor necrosis factor is only one of many cytokines produced by white blood cells in response to infections," says Elsasser. "We found that white blood cells grown in culture tubes could be stimulated to produce and release TNF when Sarcocystis was added to the culture.

"Then we found that calves infected with Sarcocystis had an elevated concentration of TNF in their blood. This finding potentially linked the response of the immune system to an effect on the endocrine system. Soon it was clear to us and others that cells throughout the body had receptors where TNF and other cytokines could attach and influence the activities of those cells," says Fayer.

To clearly establish the link between Sarcocystis, TNF production, and changes in the growth-regulating hormones, the scientists injected healthy, parasite-free calves with bovine TNF, then measured the concentrations of hormones in the blood. They found that TNF could cause changes in growth-regulating hormones parallel to those they observed in parasitized calves.

Overall, it appeared that TNF could depress bone growth, muscle growth, feed intake, and pituitary hormone secretion.

The calves' immune and hormonal responses to parasitic infection may ultimately be a mechanism for self-preservation," says Fayer. In theory, the following sequence of events takes place: The body's immune system recognizes the parasite proteins as foreign, or not belonging in the body, and the white blood cells, the first line of the body's defense, responds by secreting TNF.

TNF attaches to cells throughout the body, stimulating some and depressing the activity of others, so that nutrients and energy can be used to fight infection while maintaining just the basic life support systems.

Since energy is derived by using stored fat, carbohydrate, and proteins in muscle, growth is suppressed to conserve both energy and nutrients.

Based on this theory and the newfound understanding—at least in part—of one of the underlying molecular mechanisms of communication between the immune and endocrine systems, Elsasser and Fayer think it may be possible to come up with ways to prevent permanent damage or to restore normal function and growth to those animals that have been infected by parasites.—By **Vince Mazzola,** ARS.

SCOTT BAUER

The test tube held by zoologist Ron Fayer contains recombinant bovine tumor necrosis factor, which will be tested on cultured mouse L cells. (K4735-6)

Ronald Fayer is at the USDA-ARS Zoonotic Diseases Laboratory, 10300 Baltimore Ave., Beltsville, MD 20705-2350. Phone (301) 504-8201, fax number 504-5306. Theodore H. Elsasser is at the USDA-ARS Ruminant Nutrition Laboratory at the same address. Phone (301) 504-8281, fax number 504-8162. ◆

Have You Had Your Molybdenum Today?

Molybdenum, a little-known mineral found in beans, peas, and whole grains, keeps you alive. If it weren't for molybdenum, some of the chemicals in your body could build up to toxic levels.

But you're protected by a hardworking enzyme that relies on molybdenum. Called sulfite oxidase, the enzyme converts the unwanted chemicals to other compounds that your body can either use or get rid of.

Sulfite oxidase couldn't do this chemical chore without molybdenum. That's why the mineral warrants the status of "essential nutrient"—one that scientists have learned we can't live without.

For the most part, though, molybdenum's work as a nutrient remains a mystery. Better-known essential minerals such as calcium and iron, for instance, have a specific Recommended Dietary Allowance or RDA, like the ones you see on a box of cereal or a bottle of vitamin pills. Molybdenum has only a general range, notes ARS nutrition researcher Judith R. Turnlund.

Today's 75- to 250-microgram range of the gray-to-black mineral is "so slight it's barely visible," she says. She included amounts lower and higher than the range in a 4-month experiment at the ARS Western Human Nutrition Research Center in San Francisco. Eight healthy men aged 22 to 35 volunteered for the study.

During the experiment, they ate familiar foods like tuna salad or chicken casserole. Foods rich in molybdenum, however, were deliberately omitted from their menus.

To track molybdenum, the men were given special forms of the mineral, either as injections (three times during the study) or as an ingredient in a liquid formula served at meals. "In nature, molybdenum occurs as seven different atoms, or isotopes, each with its own atomic weight and each in an unchanging proportion to the other," explains Turnlund.

"By giving the volunteers purified doses of only two of these different molybdenum isotopes, we changed the natural ratios. That's how we traced the doses. Volunteers lived at the center for the entire study, so we could monitor everything they ate and drank. We think this is the most tightly controlled molybdenum study that's ever been done with humans."

JACK DYKINGA

Physical scientist William Keyes loads molybdenum samples for analysis by a mass spectrometer. (K4861-7)

Final results, expected later this year, may be used to set a new RDA. The experiment showcases two tests that could be streamlined for nutritionists and physicians of the future to use during vitamin-and-mineral checkups.

One option requires giving patients an extra load of any of several compounds that molybdenum-using enzymes will convert into other chemicals.

"When they were getting extra-low levels of molybdenum, says Turnlund, "we fed patients a high dose of one of these compounds. From this "loading test,' we could see that the molybdenum-using enzymes weren't getting enough of the mineral to keep up with the job of converting the compounds.

"Enzyme tests aren't new," she says, "but we're newly applying them to study molybdenum." UCLA scientist Marian E. Swendseid and former UCLA graduate student Glenn Chiang collaborated with Turnlund in this part of the experiment.

Another option relies on giving patients a dose of one of the forms of molybdenum that Turnlund used in her study. Later, a urine sample can be checked for the mineral.

The procedure Turnlund uses to hunt molybdenum—thermal ionization mass spectrometry—is too costly and cumbersome for most commercial medical labs. But newer generations of the technology should make it more affordable and easier to use, she says.

Until a test is ready and an exact RDA is set, though, how can people be sure they have all the molybdenum they need? "If you're eating three well-balanced meals a day," says Turnlund, "you're probably getting enough."

So what's the point of studying molybdenum? "If we tell people a mineral is essential," she says, "we should be able to tell them exactly how much they need. And we should have the data to back it up."—By **Marcia Wood,** ARS.

Judith R. Turnlund is at the USDA-ARS Western Human Nutrition Research Center, Micronutrients Research Unit, P.O. Box 29997, Presidio of San Francisco, CA 94129. Phone (415) 556-5662, fax number (415) 556-1432. ◆

With Tomatoes, Looking Good Isn't Enough

Nothing tastes better than a slice of red, juicy, vine-ripened tomato—by itself, or spread with creamy mayonnaise and sandwiched between two pieces of bread.

But sometimes the actual taste of that tomato slice doesn't quite measure up to consumer anticipation.

Just because a tomato is home-grown and vine-ripened doesn't mean it's going to taste good. The reason, says ARS horticulturist Elizabeth A. Baldwin, is largely flavor volatiles, along with sugar and acid content.

"Of the many volatiles identified, only a few have been singled out as important to fresh tomato aroma," she says. "And we found these present in differing amounts in six tomato varieties."

Varieties tested may differ in taste, Baldwin says, because of the different types and amounts of volatiles present.

It has been difficult to get an accurate analysis of these volatiles because of both their low concentrations and their dynamic nature: Enzymes in tomatoes cause rapid changes in volatiles.

But now Baldwin has been able to quantify 16 of the flavor components using a new gas chromatography technique that analyzes headspace, or the air above freshly homogenized laboratory samples.

Developed at the U.S. Citrus and Subtropical Products Laboratory in Winter Haven, Florida, the analysis technique was perfected by chemists Philip Shaw and Myrna Nisperos-Carriedo to analyze aroma constituents in citrus fruit and juice products. With help from Nisperos-Carriedo and chemist Manuel G. Moshonas, Baldwin modified it to work for tomatoes.

"Nine of the compounds showed significant differences among varieties," Baldwin reports. So it was on these compounds that she focused her attention.

Tomato-like flavor and the leafy, herbaceous aroma come from hexenals, the major aldehydes in tomatoes. These and other volatiles are what make a tomato smell like a tomato. Two of the varieties tested showed much higher hexenal levels than the others, she says.

Levels of ketones, the volatiles that create the fruity aroma, also showed considerable variation among the different varieties tested.

SCOTT BAUER

(K4667-6)

"Since the compounds that make a tomato taste and smell good increase during ripening, we also looked at harvest dates of the varieties we studied," Baldwin says. But she found that only the levels of hexenal showed significant differences in ripe tomatoes that were harvested green at different dates during the harvest season.

Since tomatoes are harvested green, they must be stored during a managed ripening process. Although low (55°F) temperatures are used to store tomatoes commercially, researchers are investigating the feasibility of using higher temperatures (80°F to 90°F) to delay ripening by first conditioning the fruit for longer storage. [See *"Safeguarding Winter's Food Supply,"* October 1992, pp. 18-19.]

Baldwin found that both low and high storage temperatures reduced the levels of flavor volatiles. Apparently, low temperatures somewhat lowered them, while higher temperatures were even more destructive.

Is it possible, then, to get a tomato that not only looks good, but tastes good as well?

"We think so. But," Baldwin says, "because there is so little information available on sensory variables—to define what's really good—breeders have a hard time selecting tomato varieties for flavor."

Her research may help. Jay W. Scott, a plant breeder at the University of Florida, is using Baldwin's data to produce a tomato that both tastes and looks good.

"In selecting a good breeding line for fresh-market tomatoes, breeders have always looked at yield, fruit size, lack of defects, and disease resistance," Scott explains. "All those characteristics are vitally important, but so is taste.

"I now have several tomato breeding lines planted in the field that hopefully have good traits for fresh market, including good flavor," he says. "After Baldwin analyzes these breeding lines, I'll emphasize those that are high in volatiles in my crossing work. I hope to get varieties that also have good sugar and acid levels."

A plump, juicy tomato that tastes good will be a matter of achieving a proper balance of individual flavor volatiles, sugars, and acids, Baldwin says.—By **Doris Stanley,** ARS.

Elizabeth A. Baldwin is with the USDA-ARS Citrus and Subtropical Products Laboratory, P.O. Box 1909, Winter Haven, FL 33880. Phone (813) 293-4133, fax number (813) 299-8678. ◆

Apomixis

It Could Revolutionize Plant Breeding

It looked like any ordinary forage grass, but it turned out to be a genetic treasure for E.C. Bashaw. For the buffelgrass plant discovered in a Texas pecan orchard about 30 years ago gave Bashaw, a U.S. Department of Agriculture plant geneticist, a way to use a trait called apomixis in plant breeding.

The word apomixis (pronounced AP-o-MIX-sis) comes from the Greek *apo* (from) and *mixis* (a mingling). It is asexual reproduction through seed. In apomictic plants, the embryos grow from vegetative cells without being fertilized by pollen, which contains the male sperm in plants.

Today, apomixis is being pursued by scientists with USDA's Agricultural Research Service as a tool for creating hybrids that produce generation after generation of seed that retains its vigor and produces plants identical to the female parent.

Researchers have identified apomixis in more than 35 families of plants—including more than 300 species. Apomixis is known to exist in many subtropical and tropical forage grasses, in citrus, and in wild relatives of beets, strawberries, mangos, corn, and wheat.

Since the early 1950's, Bashaw had been working with limited success on apomixis. The problem was that he hadn't been able to find a sexual plant of buffelgrass, a warm-season, drought-tolerant forage grass native to Africa. All buffelgrasses were thought to be apomictic—which ruled out cross-breeding, since the plants reproduced asexually. Without a sexual buffelgrass, there was no way to transfer genes from one apomictic plant to another—leading one prominent geneticist to call apomixis a "dead end."

And it might have been, if not for the curiosity of Pat Higgins, a seed grower who spotted what turned out to be a very rare buffelgrass plant growing in his pecan orchard in Southerland Springs, Texas, around 1960.

DOUG WILSON

Wheat, a crop where the apomixis trait would be helpful. (K3945-18)

ROB FLYNN

Plant geneticist Wayne Hanna (standing) and plant pathologist Jeffrey Wilson examine pearl millet in Hanna's research plot at Tifton, Georgia. (K3882-2)

Finding the One in a Million

The plant Higgins found in the pecan orchard was next to a field of buffelgrass introduced from Africa and planted for seed production. Since researchers believed that all buffelgrasses were apomictic, Higgins expected all the plants to be identical. They were—except for that one stray plant.

"Pat noticed that it was different," Bashaw recalls. "If he hadn't noticed that, we might have missed a great discovery."

Higgins went a step further, sowing the seeds from the stray plant. The result was dozens of plants of different sizes and shapes. He called Bashaw, who later confirmed that Higgins had found the first buffelgrass plant ever discovered to reproduce sexually. Among the wide variety of offspring were both sexual and apomictic plants.

It was a breakthrough for Bashaw, who understood the potential of apomixis but hadn't been able to take full advantage of it. Today, Bashaw and other scientists are closer to turning apomixis from a little-known reproductive mechanism into a new tool for developing improved plant varieties that retain acquired traits indefinitely. That could mean a boost in seed quality—and a more bountiful food supply.

Plant breeders want to use apomixis to lock in traits such as high yields, disease and insect resistance, and other key improvements into plants such as corn, wheat, rice, and forage crops.

Bashaw and other breeders realized that apomixis could help overcome the shortcomings of hybrids, which only retain their vigor and uniform genetic traits for one genera-

tion—meaning a farmer must buy and plant new hybrid seed each year.

If an apomictic gene could be placed in a hybrid, it wouldn't be necessary to produce new hybrid seed each year. That's because a key trait of apomictic plants is that they produce generation after generation of seed that, in turn, yield identical offspring—since they have the genetic characteristics of only their single parent. Each offspring is just as vigorous as its original female parent.

"Here was a system that could hold beneficial genes in place forever in a hybrid," Bashaw says. "And there is also great potential for transferring apomictic genes from wild species into cultivated corn, rice, wheat, and other plants."

It was considered a long shot until Higgins found the sexual buffelgrass, which could be used as the female parent in buffelgrass breeding, to unlock traits that had been fixed in apomictic buffelgrasses.

Bashaw and graduate students at Texas A&M University in College Station were eventually able to manipulate the apomictic gene in buffelgrass using the sexual plant discovered by Higgins. It was the first time plant breeders had ever accomplished this.

In fact, the grass that Higgins found became the parent of 'Higgins' buffelgrass, released in 1967. The first apomictic variety to be developed, 'Higgins' produced higher yields and more extensive roots, and it was more persistent than earlier varieties. In 1981, ARS and Texas A&M University released two more apomictic hybrid buffelgrasses, Nueces and Llano. They had even greater yields and cold tolerance than 'Higgins' and were higher in digestibility for cattle—meaning the animals would gain weight faster.

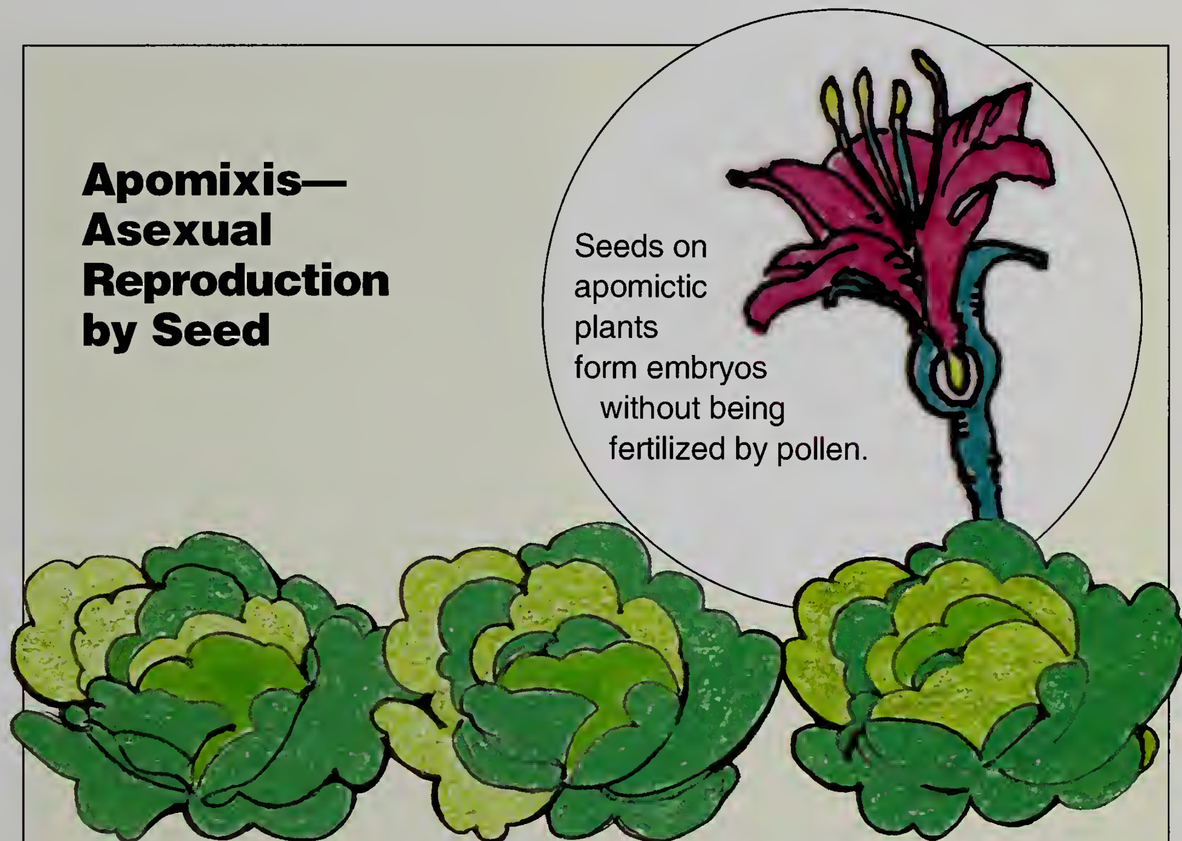
The next apomictic crop to be developed by breeders could be pearl millet, a drought-tolerant grain, says Wayne Hanna, an ARS plant geneticist at Tifton, Georgia.

Hanna got his first taste of apomixis as a graduate student at Texas A&M, where he—like Higgins—saw something that aroused his curiosity. Hanna noticed an unusual looking sorghum plant and brought it to the attention of his major professor, Keith Schertz, and to Bashaw. The sorghum plant turned out to be the first apomictic plant found in a grain crop.

Based at the Georgia Coastal Plain Experiment Station, Hanna has been working since 1978 on apomixis in pearl millet, a dryland grain crop similar to sorghum that is planted in the southern United States and on millions of acres in Africa and Asia.

He and researchers with ARS and the University of Georgia are close to developing an apomictic pearl millet. They've found that a few tightly linked genes in a single chromosome are all that may be required to transmit apomixis from the wild variety to the

Apomixis—Asexual Reproduction by Seed



Apomictic plants produce generation after generation of seed that, in turn, yield offspring that are genetically identical to the original parent.

Plant breeders want to use apomixis to lock in traits such as high yields, disease and insect resistance, and other key improvements into plants such as corn, wheat, rice, and forage crops.

cultivated one. They're using biotechnology techniques such as polymerase chain reaction to mark the apomictic genes in *Pennisetum squamulatum,* a wild relative of pearl millet, and to see if they are transferred into cultivated pearl millet, *P. glaucum,* during breeding. If they're successful, it would be the first time an apomictic gene had ever been transferred from a wild species into a cultivated grain crop.

In the summer of 1992, Hanna began screening more than 27,000 pearl millet backcrosses growing at Tifton. Initially, he explains, they developed a hybrid cross between the wild and cultivated pearl millet that contains the apomictic gene. Then, they began backcrossing—which means they crossed that original hybrid with cultivated pearl millet, trying to bring the resulting backcrosses closer to cultivated pearl millet while screening out unwanted traits from the wild relative.

Hanna says, "We have some good-looking plants that we know have the gene for apomixis, but the trouble is that many of those plants also have undesirable genes from the wild species. It takes a long time to narrow it down to the best plants."

Hanna says another benefit of apomixis is that, once an apomictic plant is developed, its traits can be bred further by putting its pollen onto a sexual plant. The breeding process can continue as long as you have a sexual plant to make the cross with.

Hanna and other apomixis researchers are setting out to clone, or duplicate, the genes for apomixis and transfer them to other plants—such as corn, rice, or wheat. "There's no reason to think it can't be done with the help of biotechnology, but it will take time," Hanna says.

Breeding apomixis into wheat is under way at Utah State University and the ARS Forage and Range

WAYNE HANNA

Rows of uniform plants grow from crosses between pearl millet and a wild relative, *Pennisetum squamulatum,* which contributes the gene or genes for apomixis. Much more breeding work must be done before these are suitable for commercial production. (K3882-3)

Research Unit in Logan, Utah, where university and ARS scientists are working with an apomictic relative of wheat called Australian wheatgrass, *Elymus rectisetus,* a wild grass native to that country. University geneticist John Carman, ARS plant physiologist Jerry Chatterton, and geneticist Richard Wang have crossed the Australian wheatgrass with cultivated wheat and are now making backcrosses. The scientists are confident that, eventually, they'll develop an apomictic wheat. But, like Hanna, they say it will take time.

"I don't think there's any question that we'll be able to do it," Chatterton says. "But it'll take a while for us to get it into a germplasm that can be used to make bread."

The same is true for getting apomictic corn into production. ARS scientists at Temple, Texas, have

begun work to transfer apomixis from a wild corn relative, called eastern gamagrass, *Tripsacum dactyloides*, into cultivated corn. As has been done with pearl millet at Tifton and with wheat at Logan, Temple researchers have made the initial crosses between corn and eastern gamagrass. Crosses were made in 1991 and 1992, and the resulting hybrids—4 the first year and about 50 in the second—are growing in greenhouses, according to Byron Burson, a plant geneticist at Temple.

"The hybrids recently began to flower, and we are in the process of determining if apomixis is expressed in any of them," he says. "We've also begun to make backcrosses with corn to move genetically closer to the commercial variety while hopefully retaining the gene for apomixis."

Burson and plant geneticist Paul Voigt, both 25-year veterans of apomixis studies, have also been investigating the phenomenon in two important forage grasses—lovegrass and dallisgrass.

But while transferring apomixis into corn, wheat, and pearl millet is under way, scientists have not thus far succeeded with rice. Before becoming associate director of the ARS Midsouth Area, J. Neil Rutger worked for 3 years in the agency's Crops Pathology and Genetics Research Unit in Davis, California, trying to find apomixis in rice. Although unsuccessful, Rutger believes someone will eventually succeed and that apomictic hybrids will be developed.

"That would be particularly important in rice, because rice is highly self-pollinating and we haven't been able to produce hybrids in this country," he says. "The Chinese produce rice hybrids, but it's very costly and labor-intensive and their grains aren't of high enough quality for U.S. markets. With apomixis, we could produce higher quality rice hybrids."

Inducing Sexual Reproduction

If sexual varieties can't be found for breeding with apomictic ones, there may be another alternative: inducing sexual reproduction in apomictic plants. At the agency's U.S. Regional Pasture Research Laboratory in University Park, Pennsylvania, scientists have shown that certain salts can actually induce apomictic plants to develop sexual embryos.

Plant pathologist Robert T. Sherwood, plant physiologist David L. Gustine, and microbiologist Yannis Gounaris, in cooperation with Penn State University scientists, were the first to show that an apomictic plant could be made to reproduce sexually by stressing it with salts.

The scientists are not certain why this occurs, but it may be because salt gives the upper hand to sexual embryo sacs inside the plant. These sacs are equivalent to the uterus in the human female. Sherwood says apomictic plants have both sexual and apomictic sacs, but that usually the apomictic embryos are dominant and the sexual sacs wither away and never develop. The salt, however, appears to reverse this, allowing the sexual sacs to outcompete the apomictic ones.

The researchers at University Park have also found that apomixis in buffelgrass—their model system—appears to be controlled by a single gene. "This finding is important because it tells us it should be possible to isolate that gene using biotechnology and then insert it into related sexual plants so that they will have apomictic reproduction," he says.

Those plants may not be producing food until the 21st century—long after Pat Higgins found that stray buffelgrass plant—but at least apomixis is no longer a dead end for breeders.—By **Sean Adams**, ARS.

To reach ARS scientists mentioned in this article, contact Sean Adams, USDA-ARS, Room 435, 6303 Ivy Lane, Greenbelt, MD 20770. Phone (301) 344-2723, fax number (301) 344-2311. ◆

Testing Fumonisin Activity

Fumonisins are recently discovered mycotoxins, or metabolic byproducts, made by the molds *Fusarium moniliforme* and *F. proliferatum.*

South African researchers were the first to describe fumonisins in 1988. In the same year, ARS chemist Ronald D. Plattner, at the National Center for Agricultural Utilization Research (NCAUR) in Peoria, Illinois, was the first scientist to isolate fumonisins from U.S. corn.

Fumonisin B_1 has been implicated in outbreaks of equine leukoencephalomalacia (ELEM) and swine pulmonary edema. [See *"Corn Mold Hazard,"* August. 1990, p. 27.]

The effect of fumonisins on poultry is not known, but ongoing research at Peoria may yield information to help establish guidelines. And researchers at the Richard B. Russell Research Center in Athens, Georgia, are using rats as a model for investigating the toxin's effects on organs and tissues.

At NCAUR, some unusual blood donors—turkeys—are contributing to fumonisin studies. ARS chemist Mary Ann Dombrink-Kurtzman is collecting blood from 8- to 16-week-old Nicholas broad-breasted whites residing on a central Illinois farm. She began these studies in March 1991.

"Turkeys have veins close to the surface of their wings similar to the veins in human arms where blood is usually drawn. It's necessary to use fresh blood to obtain cells suitable for testing," says Dombrink-Kurtzman.

After exposing the turkey lymphocytes—a type of white blood cell—to purified fumonisins, Dombrink-Kurtzman adds a tetrazolium salt known as MTT. The living blood cells contain a dehydrogenase enzyme that converts MTT (yellow) to MTT formazan (blue). To measure the effect of the fumonisins, she compares the intensity of the blue color of the exposed cells to that of unexposed controls.

The MTT test is an alternative to testing with whole animals. "If we can see the effect the toxin has at the cellular level, then we can predict what may be happening in the whole animal," says Dombrink-Kurtzman.

Use of the MTT test was the brainchild of John L. Richard. Formerly a member of the Pathology Unit at ARS' National Animal Disease Center in Ames, Iowa, he now heads NCAUR's Mycotoxin Research Unit. Richard has applied this test to other mycotoxins, such as gliotoxin and T-2 toxin.

While fumonisins are not regulated as food or feed hazards by USDA's Food Safety and Inspection Service or the Food and Drug Administration, results of the ARS studies are available to these agencies, which are responsible for monitoring the safety of the U.S. food supply.—By **Linda Cooke,** ARS.

Mary Ann Dombrink-Kurtzman and John L. Richard are in the USDA-ARS Mycotoxin Research Unit, National Center for Agricultural Utilization Research, 1815 N. University Street, Peoria, IL 61604. Phone (309) 685-4011, fax number (309) 671-7814. ◆

Weather Network Helps Protect Crops, Cut Irrigation

Last year, Colorado onion growers who followed reports from a new statewide network of weather stations escaped fungusborne crop diseases that hit other growers who farmed as usual.

The reports gave warning to apply fungicides because near-ideal weather conditions were about to make possible an explosive fungal growth.

The network can also give growers a similar jump on fighting insect infestations.

And, "Because it provides much more detailed weather information across the state, the network can help growers fine-tune the amount of irrigation water they apply and perhaps reduce water use in some areas by up to 30 percent," says ARS agricultural engineer Harold R. Duke.

Key to the new 22-station network are standardization of equipment and timely interpretation of data. Previously, scientists had to use several-days-old data from only eight existing stations. And the stations did not always collect the same types of weather details.

This new network is a cooperative effort between ARS and Colorado State University. It has already shown it is possible to predict insect and disease outbreaks by using timely weather data and an advanced computer program. The computer analyzes the data to predict how many crop pests will be affected.

Originally developed for high-value crops like onions and beans, the program could be expanded in the future to provide information for all crops in the state.

The weather stations cost about the same as other, less sophisticated types on the market—$5,500. Each station daily records such weather-related information as minimum and maximum temperatures, vapor pressure, solar radiation, total wind movement during the day, precipitation, soil temperature, and minimum relative humidity.

A computer in Harold Duke's office in Fort Collins automatically calls each station between 2 and 4 a.m. to retrieve this information. It takes each station about 1 minute to download its stored weather data.

"We are using cellular telephones to connect some weather stations in the network. Previously we were forced to install expensive direct telephone wire lines to stations or choose less desirable locations closer to existing phone lines," says Duke. U.S. West, a local cellular company, has waived the usual monthly charge and reduced per-minute fees to 17 cents.—By **Dennis Senft,** ARS.

Harold R. Duke is in the USDA-ARS Water Management Research Unit, Agricultural Engineering Research Center, Colorado State University, Fort Collins, CO 80523. Phone (303) 491-8230, fax number (303) 491-8247. ◆

Science Update

School Kids Learn About Biocontrol

American students got a bug's eye view of biological pest control February 4 during a live satellite TV broadcast. The broadcast showed how scientists at Colorado State University and the ARS lab in France find and test beneficial bugs as controls for pesky weeds and insects. Students at more than 10,000 schools watched ladybugs and wasps prey on Russian wheat aphids and other insect pests. Live Educational Resource Network, Inc., Denver, Colorado, produced the program. *Richard S. Soper, assistant ARS administrator for international research programs, Beltsville, Maryland. Phone (301) 504-5605.*

Meat Microbes Succumb to Irradiation

In the West last Winter, two children died and more than 400 other people got sick from eating beef patties tainted with a bacterium, *Escherichia coli* 0157:H7. ARS scientists have found that irradiating ground beef—at levels far below those federally approved for poultry—could cut the risk of such outbreaks. Large-scale tests are needed before USDA can ask the Food and Drug Administration to approve irradiation of beef. But this safe method of food protection is now used for spices and strawberries and is also approved for other fruits and vegetables, pork, and poultry. *Donald W. Thayer, Food Safety Research Unit, Eastern Regional Research Center, Philadelphia, Pennsylvania. Phone (215) 233-6583.*

Smoking Cuts Milk Production in Nursing Mothers

For new mothers who smoke, here's another reason to crush that cigarette: If you're breast-feeding, your infant may get shortchanged on milk calories. In the 2 to 4 weeks after their babies were born, nursing mothers who smoked produced 22 percent less milk than nonsmokers. *Judy M. Hopkinson, Children's Nutrition Research Center, Houston, Texas. Phone (713) 798-7008.*

Ambersweet Wins FDA Approval

The Food and Drug Administration has ruled that Ambersweet, a superior ARS orange hybrid, can be used freely in processed orange juice. This greatly widens the market for Ambersweet, now grown on 20,000 acres in Florida, because it will cut U.S. juicemakers' import and storage costs. In the past, juicemakers met quality needs by relying on blends of stored frozen Valencia orange juice or imports from Brazil. Now they can get equal or better quality by using Ambersweet for blends—or all by itself. Ambersweet's lineage is half orange, three-eighths tangerine, and one-eighth grapefruit. *C. Jack Hearn, Citrus and Subtropical Products Research Laboratory, Winter Haven, Florida. Phone (813) 293-4133.*

RANDALL SMITH

Ambersweet oranges. (K3644-12)

A New Use for Old Phone Books?

This spring, tons of old phone books will reach out and touch some...soil. ARS and Auburn University scientists will shred and plow under last year's phone directories for Lee County, Alabama. After beneficial soil microorganisms digest the paper fiber, hard-packed soil should become crumbly and allow easy penetration by roots of corn, cotton, and soybeans. This could give towns a new way to recycle paper waste—instead of dumping it in near-capacity landfills. *James Edwards, Soil Dynamics Research Laboratory, Auburn, Alabama. Phone (205) 844-3979.*

Radio Implant Monitors Bossie's Health

In the future, a dairy cow may go on radio to alert the farmer that she's coming down with mastitis—a bacterial infection of the udder—or other diseases that cut milk production and cause her discomfort. A tiny sensor, placed harmlessly in the udder, records the cow's temperature; a mini-transmitter relays the data to a computer every 15 minutes. Temperature changes often signal the onset of disease, but the new system can sense a health problem before symptoms appear. That could reduce veterinary costs and speed the cow's recovery. *Alan M. Lefcourt, Milk Secretion and Mastitis Laboratory, Beltsville, Maryland. Phone (301) 504-8451.*

And Now, Designer Oats!

Oat plants have been gene engineered for the first time by ARS and University of Minnesota scientists. This raises prospects for redesigning oats to resist disease better and produce more nutritious grain. *Howard W. Rines, Plant Science Research, St. Paul, Minnesota. Phone (612) 625-5220.*

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